



ATO

AIR TRAFFIC ORGANIZATION

NATIONAL AIRSPACE SYSTEM

System Engineering Manual

*Federal Aviation Administration
ATO Operations Planning*

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Date

October 11, 2006

REVISION RECORD		
Version	Description	Date
1.0	Initial Issue	11/01/02
2.0	<ul style="list-style-type: none"> • Re-wrote chapter and 3 • Added 4.8.2, 4.8.3, 4.8.4, 4.8.6, 4.8.7 • Re-wrote 4.8.10 • Resolved various comments on remaining v1.0 	9/30/03
3.0	<ul style="list-style-type: none"> • Re-wrote 4.2 Integrated Technical Planning • Re-wrote 4.3 Requirements Management • Re-wrote 4.8.1 System Safety Engineering • Re-wrote 4.8.4 Electromagnetic Environmental Effects • Added 4.8.5 Quality Engineering • Re-wrote 4.8.6 Information Security Engineering • Re-wrote 4.10 Risk Management • Added 4.11 Configuration Management • Added 4.13 Lifecycle Engineering • Added 4.14 SE Process Management • Added two appendices – Requirements Management Resources and SE Templates • Updated other sections as necessary to address specific comments received via the SEM comment process 	9/30/04
3.1	<ul style="list-style-type: none"> • Updated entire SEM except 4.6, Trade Studies, and 4.12, Validation and Verification, to reflect the AMS policy changes (Nov. 2004) • Reviewed entire SEM for harmonization between sections and made changes where appropriate, including the N² in Chapter 3.0 • Added “System of Systems” discussion to Chapter 2.0, Overview of System Engineering • Rewrote Chapter 3.0, System Engineering in the Acquisition Management System Program Lifecycle, incorporating contents of Appendix F, Acquisition Management System Lifecycle Phase and Associated System Engineering Element Work Products • Added “Technical Measures and Control” section to 4.2, Integrated Technical Planning • Rewrote section 4.13, Lifecycle Engineering • Added “tailoring” discussion (formerly in section 3.5) to 4.14, System Engineering Management Process • Revised Appendices A - Acronyms and B - Glossary to reflect changes in rest of document • Added Appendix C - SE Technical Reviews and Associated Checklists • Deleted Appendix F - Acquisition Management System Lifecycle Phase and Associated System Engineering Element Work Products 	10/11/06

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Preface

Objective

The FAA System Engineering Manual (SEM), version 3.1, aligns with the current decision-making paradigm in the FAA Acquisition Management System. The SEM provides a framework for implementing system engineering across the FAA. The intended audience includes the new systems engineer, an engineer in another discipline who needs to perform system engineering, and the experienced systems engineer who needs a convenient reference to implement the practice within the FAA context.

This SEM describes a set of standard practices combined with industry and government "best practices" to implement system engineering in the context of the National Airspace System, both from acquisition and operational perspectives. The relevance of these processes and practices will vary widely, depending on the complexity, size, objectives, and point in the product lifecycle a project or organization may find itself. Some aspects will be effectively handled informally; others will require a high degree of discipline and rigor.

This document is not intended to mandate any level of formality as necessary or appropriate in all situations. Within certain bounds, the implementing organization can best determine the appropriate degree of implementation. Section 4.14 (System Engineering Process Management) presents recommended tailoring guidelines to achieve the proper balance between technical objectives, business objectives, and process implementation.

Acknowledgments

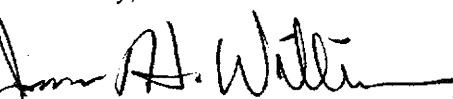
The FAA System Engineering Council owes a debt of gratitude to all the contributors to prior SEM editions (versions 1.0, 2.0, and 3.0). The framework they provided has been a solid basis for implementing system engineering across the FAA. However, SEM version 3.1 includes significantly more information than previous versions.

We want to thank the SEM review team members—who also served as principal authors—for their dedication and enthusiasm in melding the contributions of many other authors into a coherent document and implementation framework. The review team members included Ken Kepchar, Cheryl Souders, and Linda Suppan and were supported by Eric Weill.

It would be difficult to accurately characterize the specific contributions of each of the authors, reviewers, and support personnel because several served multiple roles. We wish to acknowledge them in alphabetical order: George Barboza, Basilyn Bunting, Gail Frazier, Steve French, Glen Hewitt, John Horrocks, Clarence M. Johnson, Shirley McGowan, Ron Stroup, and Danette Warren. In addition, representatives from the International Council on Systems Engineering provided valuable inputs and comments.

We apologize in advance if we—in our final rush to publish—omitted anyone from this list.

Gratefully,



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1 INTRODUCTION

The System Engineering Manual (SEM) is a “how to” guidebook. The SEM defines major System Engineering (SE) elements and establishes best practices regarding application of these elements to the National Airspace System (NAS). The SEM is a selected compilation of those proven practices within the SE domain that are deemed most appropriate to analysis, planning, design, acquisition, lifecycle support, and management of Federal Aviation Administration (FAA) programs.

There are many definitions of SE in textbooks, professional journals, and classrooms. The following definition has been selected for the SEM:

SE is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspects.

SE addresses translation of stakeholder needs into system requirements and facilitates the process by which the specification of systems and/or components satisfies those requirements. Although programs differ in underlying requirements, SE provides a logical sequence of steps toward deriving good requirements and transforming them into solutions regardless of the program's size or complexity. These steps generate a series of work products that specify characteristics of systems (at any level), demonstrate and document traceability to stakeholder needs (expressed or implied), and define how the requirements are validated and the systems (and associated components) are verified. To maximize effectiveness, SE commences before any significant product development activities and continues throughout the program's lifecycle. When performed correctly, SE helps to ensure that program execution is right from the start. Any problems are detected and resolved early. This process reduces program cost and risk.

1.1 Purpose

The primary purposes of this manual are to:

- Define the FAA's integrated practice of SE to be used by any engineer or group performing a task requiring an SE approach; by design, this practice is compatible with all components of the agency and consistent with sound government and industry best policies and guidelines
- Provide methods and tools that result in effective and consistent SE
- Identify competency areas for the effective practice of SE
- Supply detailed information on work products of SE activities that are needed to ensure uniform and consistent high-quality products
- Enable SE to participate in and support Program Management and its needs

1.2 Scope

The SEM describes 12 major SE elements as they are applied within the FAA. The SEM supports the Acquisition Management System (AMS) by identifying the proper application of SE elements in the AMS decision and acquisition processes. Figure 1.2-1 shows the 12 SE elements. A 13th element can be considered to be “Maintain Systems Engineering.”

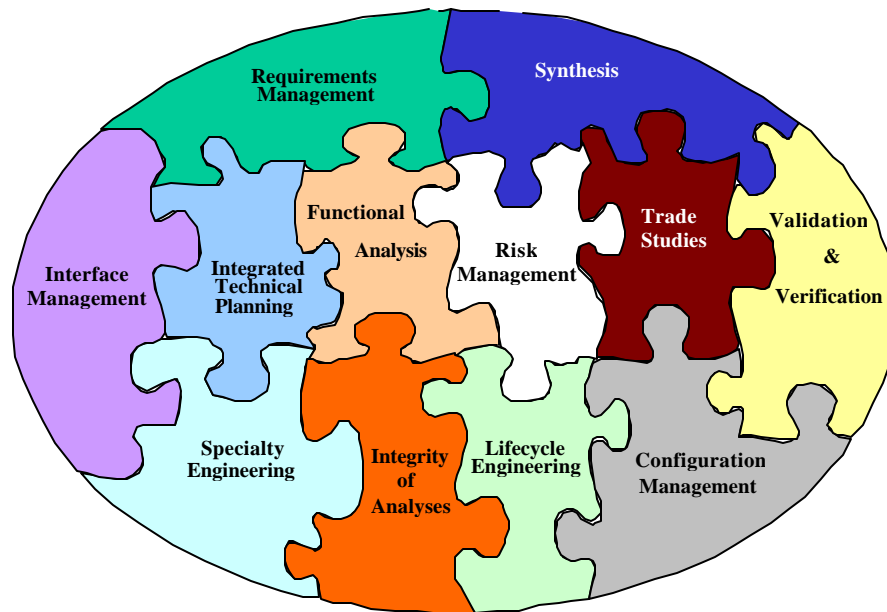


Figure 1.2-1. FAA System Engineering Elements

As a “how to” manual for SE, the SEM defines the constituent SE elements to be performed throughout the program lifecycle. The term “program” is intended to mean projects of all sizes and complexity, ranging from the National Airspace System (NAS) to individual parts. While the SEM is primarily directed at NAS modernization, it is recommended that individual programs tailor the application of processes, tools, and techniques according to program requirements. Further, implementation of these processes is to be directed by the appropriate program or SE management authority designated in the NAS System Engineering Management Plan (SEMP). The SEM includes guidance on tailoring (see Section 4.14, System Engineering Process Management).

The SEM defines the FAA SE elements as well as the work products generated from each SE element. The 12 (actually 13) elements appear in Table 1.2-1 along with each element’s purpose or function. The 13th element listed provides for process management and maintenance of the other 12 elements.

Table 1.2-1. System Engineering Elements

System Engineering	Abbrev.	Purpose of Element
Integrated Technical Planning	ITP	Plans the SE efforts and products.
Requirements Management	RM	Identifies and manages the requirements that describe the desired characteristics of the system.
Functional Analysis	FA	Describes the functional characteristics (what the system needs to do) that are used to derive requirements.
Synthesis	SYN	Transforms requirements into physical solutions.
Trade Studies	TS	Assists decision making by analyzing and selecting the best-balanced solutions to requirements.
Interface Management	IM	Identifies and manages the interactions between segments within a system or interactions with other peer systems.
Specialty Engineering	SpecEng	Analyzes the system, requirements, functions, solutions, and/or interfaces using specialized skills and tools. Assists in derivation of requirements, synthesis of solutions, selection of alternatives, and validation and verification of requirements.
Integrity of Analyses	IA	Ensures that analyses provide the required level of fidelity and accuracy.
Risk Management	RSK	Identifies, analyzes, and manages the uncertainties of achieving program requirements by developing strategies to reduce the severity or likelihood of those uncertainties.
Configuration Management	CM	Establishes and maintains consistency and manages change in the system performance, functional, and physical attributes.
Validation and Verification	V&V	Validation determines if system requirements are correct. Verification determines that the solution meets the validated requirements.
Lifecycle Engineering	LCE	Identifies and manages requirements for system lifecycle attributes, including real estate management, deployment and transition, integrated logistics support, sustainment/technology evolution, and disposal.
Maintain System Engineering Process	MSE	Manages and maintains SE processes to meet FAA goals. Gains agency-wide skill and standardization by continuously improving the effectiveness and efficiency of SE processes and tools.

1.3 Organization of the Manual

In addition to the purpose, scope, and manual organization, Chapter 1 discusses the relationship between the SEM and SEMP, SE process descriptions, and the interaction between SE elements. Chapter 2 discusses the historical background and context for the practice of SE. Chapter 3 describes the relationship between the SEM and each phase of the FAA AMS. Chapter 4 contains individual sections that discuss in detail each major SE element and interrelationships among the elements. Also included is a correlation between each SE element (with its associated Chapter 4 paragraph number) and the reference to the associated section of the FAA Integrated Capability Maturity Model (iCMM) (e.g., SEM 4.12; iCMM PA 08) and/or Electronics Industries Alliance (EIA)-731.1 (e.g., SEM 4.2; EIA-731 Functional Area 2.1).

The following appendices are included:

- Appendix A: Acronyms and Abbreviations
- Appendix B: System Engineering Manual Glossary
- Appendix C: System Engineering Technical Reviews and Associated Checklists
- Appendix D: Concerns and Issues
- Appendix E: Integrated Technical Planning Details
- Appendix F: Reserved
- Appendix G: Requirements Management Resources

1.4 Relationship Between the SEM and the SEMP

The SEM and SEMP are designed to work together. The SEM answers SE questions related to what, how, and when, while the SEMP answers SE questions related to what, who, when, and why (i.e., why a particular organization or program is implementing or not implementing a particular SE element versus the SEM discussion regarding an SE element's purpose). The “what,” or products and activities of SE, directly connects the SEM and SEMP, and the “when” provides a secondary correlation. Figure 1.4-1 portrays this relationship between the SEM and SEMP.

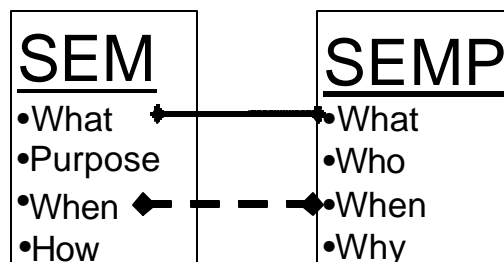


Figure 1.4-1. Relationship Between the SEM and the SEMP

1.5 System Engineering Process Descriptions

The SE process descriptions in Chapter 4 include the following information:

- **Process Definition.** This narrative discusses the function for the process (what to do). The purpose for carrying out the specific SE process and a description of the specific SE process are included. Program implementers may use this information to tailor specific activities to align them with the development events of the program.
- **Process-Based Management (PBM) Charts.** Each SE element section in Chapter 4 uses PBM charts to describe the SE element process. The PBM charts indicate the major steps of the SE process; inputs to the process and associated providers; possible outputs generated; and associated product customers (from an SE view). The SEM also identifies the supplying (inputs) and using (outputs) processes that are used during process implementation to establish program communication, documentation, and review activities.

The granularity of both input and output products depends on the phase of the AMS lifecycle to which the particular SE element being discussed is applied. For example, Synthesis results are emphasized more in Solution Implementation than during Mission Analysis.

The process descriptions consist of all aspects of each SE process, including the need to design for safety, security, affordability, performance, usability, operational suitability, and cost of ownership. On some programs, a given activity may be performed informally (e.g., in an engineer's notebook) or formally with interim products under formal baseline control.

Each SE process includes these major workflow tasks, which are also shown on the PBM charts.

- **How To Do It.** The SEM discusses specific approaches or techniques for implementing each SE process and provides guidance for selecting the right approach for a given program phase. It summarizes the key points, focusing on the “what” and “when,” as well as the “how.”
- **Inputs.** These include information from external sources or other processes that initiate the process or are received during the conduct of the process.
- **Outputs.** These include information developed during the process and by conducting the process.
- **Beginning Boundary Task (Entrance Criteria).** This is what is required to start the process.
- **Ending Boundary Task (Exit Criteria).** This is what is required to complete the process and allow legitimate exit from the process.
- **Metrics.** These include examples of metrics for measuring the level of performance for the process, as well as the work products generated by the process.
- **Methods/Tools.** This category includes specific tools or methods that are necessary (or desirable) to efficiently implement the process as described. It also lets the user know what is available within the AMS FAA Acquisition System Toolset (<http://fast.faa.gov/>).
- **Examples.** These include both SE work products and the standard templates for producing the SE work products. Examples may be contained either within a particular section of Chapter 4, an appendix to the SEM, or on the FAA's intranet, in which case a reference Web address is provided.

- **References.** This subsection includes documents from the government, industry, and academia that cover relevant topics regarding that section.

1.6 Process-Based Management and System Engineering

It is very difficult to develop a generic, top-level process model that reflects all interactions among the processes for the SE elements shown in Table 1.2-1 above. The interactions and iterations between the SE elements may be different depending on the program under consideration. Chapter 3 contains a definition of the SE milestones and interactions with each of the major phases of the AMS (i.e., Mission Analysis, Investment Analysis, Solution Implementation, In-service Management, and Disposal). In addition, Chapter 3 Figure 3.1-2, System Engineering Functional N-Squared (N^2) Diagram, contains an N^2 diagram that depicts the interrelationships, inputs, outputs, and products from the related processes.

2 OVERVIEW OF SYSTEM ENGINEERING

This section traces several key developments and lessons learned that led to today's championing of System Engineering (SE) as a powerful approach to organizing and conducting complex programs, such as those in the National Airspace System (NAS). SE continues to evolve, emphasizing stronger commercial- and team-based engineering organizations as well as organizations without technical products. Before World War II, architects and civil engineers were, in effect, system engineers who worked on large, primarily civil, engineering projects—including the Egyptian pyramids, Roman aqueducts, Hoover Dam, the Golden Gate Bridge, and the Empire State Building—while other architects worked on trains and large ships. However, “early” system engineers operated without any theory or science to support SE. Thus, they lacked defined and consistently applied processes or practices. During World War II, a program manager and chief engineer might oversee development of an aircraft program, while others managed key subsystems, such as propulsion, controls, structure, and support systems. This led to a lack of uniformity throughout the process.

Some additional SE elements, such as operations research and decision analysis, gained prominence during and after World War II. Today, with more complex requirements and systems, chief engineers use SE to develop requirements and to integrate the activities of the program teams.

SE began to evolve as a branch of engineering during the late 1950s. At this time—when both the race to space and the race to develop missiles equipped with nuclear warheads were considered absolutely essential for national survival—the military services and their civilian contractors were under extreme pressure to develop, test, and place in operation nuclear-tipped missiles and orbiting satellites. In this climate, the services and their contractors sought tools and techniques to improve system performance (mission success) and program management (technical performance, delivery schedule, and cost control). Engineering management evolved, standardizing the use of specifications, interface documents, design reviews, and formal configuration management. The advent of hybrid and digital computers permitted extensive simulation and evaluation of systems, subsystems, and components that facilitated accurate synthesis and tradeoff of system elements.

The lessons learned with development programs led to innovative practices in all phases of high-technology product development. A driving force for these innovations was attainment of high system reliability. Some examples of changes introduced during the period are:

- Requirements traceability
- Parts traceability
- Materials and process control
- Change control
- Product accountability
- Formal interface control

2.1 What Is System Engineering?

Beyond the definition used in the Introduction (Chapter 1), SE is an overarching process that trades off and integrates elements within a system's design to achieve the best overall product and/or capability known as a system. Although there are some important aspects of program management in SE, it is still much more of an engineering discipline than a management

discipline. SE requires quantitative and qualitative decision making involving tradeoffs, optimization, selection, and integration of the results from many engineering disciplines.

SE is iterative—it derives and defines requirements at each level of the system, beginning at the top (the NAS level) and propagating those requirements through a series of steps that eventually leads to a physical design at all levels (i.e., from the system to its parts). Iteration and design refinement lead successively to preliminary design, detail design, and final approved design. At each successive level, there are supporting lower level design iterations that are necessary to gain confidence for decisions. During these iterations, many concept alternatives are postulated, analyzed, and evaluated in trade studies, resulting in a multi-tier set of requirements. These requirements form the basis for structured verification of performance. SE closely monitors all development activities and integrates the results to provide the best solution at all system levels.

2.2 What Is a System?

A system is an integrated set of constituent parts that are combined in an operational or support environment to accomplish a defined objective. These integrated parts include people, hardware, software, firmware, information, procedures, facilities, services, and other support facets. People from different disciplines and product areas have different perspectives on what makes up a system. For example, software engineers often refer to an integrated set of computer modules as a system. Electrical engineers might refer to a system as complex integrated circuits or an integrated set of electrical units. The FAA has an overarching system of systems called the NAS that includes, but is not limited to, all the airports; aircraft; people; procedures; airspace; communications, navigation, and surveillance/air traffic management systems; and facilities.

It is difficult to agree on what comprises a system since it depends entirely on the focus of those who define the objective of the system. If the objective is to print input data, a printer may be defined as the system. Expanding the objective to processing input data and displaying the results yields a computer as the system. If we expand the objective further to include a capability for computing nationwide or worldwide data and merging data/results into a database, then a computing network becomes the system, with the computer and printer(s) as subsystems of the system.

A concept that has received considerable attention in recent years has been that of a system of systems, which can be described as the composite interaction of independent complex systems. There are several definitions of System of Systems (SOS) as opposed to the component systems that comprise an SOS, depending on the domain or application of interest. For example, ISO 15288 discusses a system in the context of its operational environment and makes the point that within a system hierarchy, any component can be a system in its own right, with all the characteristics ascribed to a system.¹ The Defense Acquisition University (DAU) asserts that:

“System of systems engineering deals with planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system of systems capability greater than the sum of the capabilities of the constituent parts. It is a top-down, comprehensive, collaborative, multidisciplinary, iterative, and concurrent technical management process for identifying system of systems capabilities; allocating such capabilities to a set of interdependent systems; and coordinating and integrating all the necessary development, production,

¹ ISO/IEC 15288:2002(E), page 52.

sustainment, and other activities throughout the life cycle of a system of systems. The overall objective for developing a system of systems is to satisfy capabilities that can only be met with a mix of multiple, autonomous, and interacting systems. The mix of constituent systems may include existing, partially developed, and yet-to-be-designed independent systems.”²

While there is not consensus on a single definition, there appears to be convergence on some common characteristics or issues that SE must pay particular attention to in this context:

- The issue of scale, often discussed as “large-scale systems integration”
- The added degree of complexity over that of the component systems
- Interoperability and boundaries across the System of Systems, which drives an increased focus on the control of interfaces between the component systems

An SOS should be treated and managed as a system in its own right and should therefore be subject to the same SE processes and best practices applied to individual systems. The NAS can be characterized as a “system of systems” by any of these measures. The FAA defines the NAS as the overall environment in which aircraft operate, including aircraft, pilots, tower controllers, terminal area controllers, en route controllers, oceanic controllers, maintenance personnel, and airline dispatchers, as well as the associated infrastructure (facilities, computers, communications equipment, satellites, navigation aids, and radars). For the purposes of this SEM, the NAS will be treated as a system, recognizing that the SOS characteristics above require specific treatment, especially at the NAS level.

SE first defines the system at the top level, ensuring focus and optimization at that level. It then proceeds to increasingly lower levels of detail until the system is completely decomposed to its basic elements. The following subsection describes the hierarchy.

2.2.1 Hierarchy

A system may include hardware, software, firmware, people, information, techniques, facilities, services, and other support items. Figure 2.2-1 establishes a common reference for discussing the hierarchy of a system/subsystem within the NAS. Each system item may have its own associated hierarchy. For example, the various software programs/components that may reside in a system have a commonly accepted hierarchy as depicted in Figure 2.2-2. Thus, Figure 2.2-2 is a subset of Figure 2.2-1 in that a system/subsystem may have multiple Computer Software Configuration Items (see definitions next page). The depths of this common hierarchy may be adjusted to fit the complexity of the system. Simple systems may have fewer levels in the hierarchy than complex systems and vice versa. Because there may be varying hierarchal models referenced in the realm of SE, it is important for those who define the objective or function of a given system/subsystem to also lay out the hierarchal levels of the system in order to define the system’s scope.

Following are definitions for succeeding levels within the system/subsystem hierarchy used in this SEM:

- **System.** An integrated set of constituent parts that are combined in an operational or support environment to accomplish a defined objective. These parts include people, hardware, software, firmware, information, procedures, facilities, services, and other support facets.

² Defense Acquisition Guidebook Web site: akss.dau.mil/DAG/GuideBook/IG_c4.2.6.asp

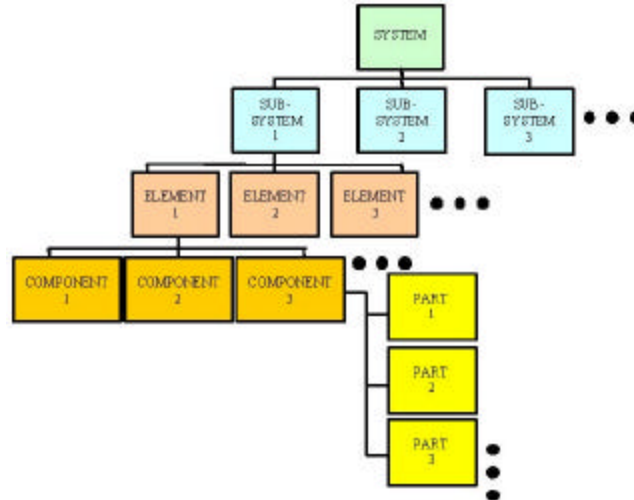


Figure 2.2-1. System Hierarchy

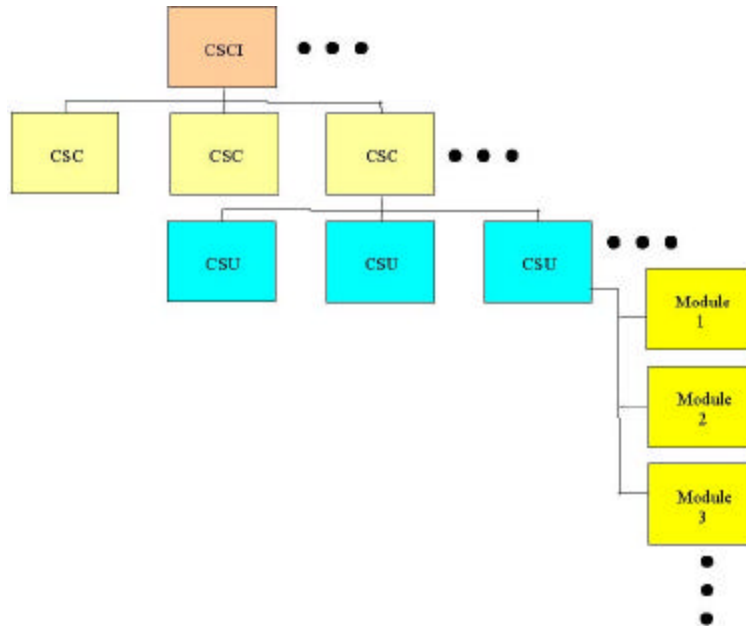


Figure 2.2-2. Common Software Hierarchy

- **Subsystem.** A system in and of itself (reference the system definition) contained within a higher level system. The functionality of a subsystem contributes to the overall functionality of the higher level system. The scope of a subsystem's functionality is less than the scope of functionality contained in the higher level system.
- **Element.** An integrated set of components that comprise a defined part of a subsystem (e.g., the fuel injection element of the propulsion subsystem).
- **Component.** Composed of multiple parts; a clearly identified part of the product being designed or produced.

- **Part.** One, two, or more pieces joined together to make a component; these pieces? the lowest level of separately identifiable items within a system—are not normally subject to disassembly without destruction or impairment of designed use.
- **Software.** A combination of associated computer instructions and computer data definitions required to enable the computer hardware to perform computational or control functions.
- **Computer Software Configuration Item (CSCI).** An aggregation of software that is designed for configuration management and treated as a single entity in the Configuration Management process (Section 4.11).
- **Computer Software Component (CSC).** A functionally or logically distinct part of a CSCI, typically an aggregate of two or more software units.
- **Computer Software Unit.** An element specified in the design of a CSC that is separately testable or able to be compiled.
- **Module.** A program unit that is discrete and identifiable with respect to compiling, combining with other units, and loading.

2.3 Why Use System Engineering?

The most important reason to apply SE is that it provides the context, discipline, and tools to adequately identify, define, and manage all system requirements in a balanced manner. It provides the disciplines required to produce a complete solution concept and system architecture. It also provides the discipline and tools to ensure that the resulting system meets all requirements that are feasible within specified constraints. No other engineering or management discipline explicitly provides this comprehensive context or results. The need for effective SE is most apparent with large, complex system developments, such as weapons and transportation systems. However, SE is also important in developing, producing, deploying, and supporting much smaller systems, such as cameras and printers. The growing complexity in development areas has increased the need for effective SE. For example, about 35 years ago in the semiconductor industry, a single chip was no more complex than a series of a few gates or, at most, a four-stage register. Today, Intel's Pentium® processor is far more complex, which immensely expands the application horizon but demands far more sophisticated analysis and discipline in design.

The movement to concurrent engineering as the technique for performing engineering development is actually performing good SE. SE provides the technical planning and control mechanisms to ensure that the activities/results of concurrent engineering meet overall system requirements.

A driving principle for SE is the teaming that often occurs during development programs. In this case, teaming is among several entities that may have different tools, analysis capabilities, and so on. SE principles defined in this manual may provide an improved ability to plan and control activities that require interaction and interfacing across boundaries. The strongest argument for using the SE processes is that they increase the likelihood that needs may be fully and consistently met in the final product.

3 SYSTEM ENGINEERING IN THE ACQUISITION MANAGEMENT SYSTEM PROGRAM LIFECYCLE

3.1 Introduction

This chapter discusses the relationship between the System Engineering (SE) milestones and the phases and lifecycle management decisions of the Acquisition Management System (AMS). The inputs and outputs for each SE element are related to each (AMS) phase through the SE milestones shown in Figure 3.3-1, and the elements and products are associated with the AMS decision points.

This System Engineering Manual (SEM) reflects industry and government SE standards, methodologies, and best practices. It recognizes that the current state of the referenced AMS, SE documents, and processes herein may not be in total agreement because that documentation and the SEM are in different update cycles. This version of the SEM reflects the changes that have been made to the AMS to incorporate the Office of Management and Budget (OMB) Exhibit 300 process.

This chapter includes graphical depictions of the inputs, SE activities, and outputs of each AMS phase. Tailoring guidance for the SE process to a particular program that was contained in this chapter in previous versions of the SEM is now found in Section 4.14, System Engineering Process Management.

3.1.1 The FAA Lifecycle Management Process

Figure 3.1-1 depicts the FAA AMS Lifecycle Management Process.

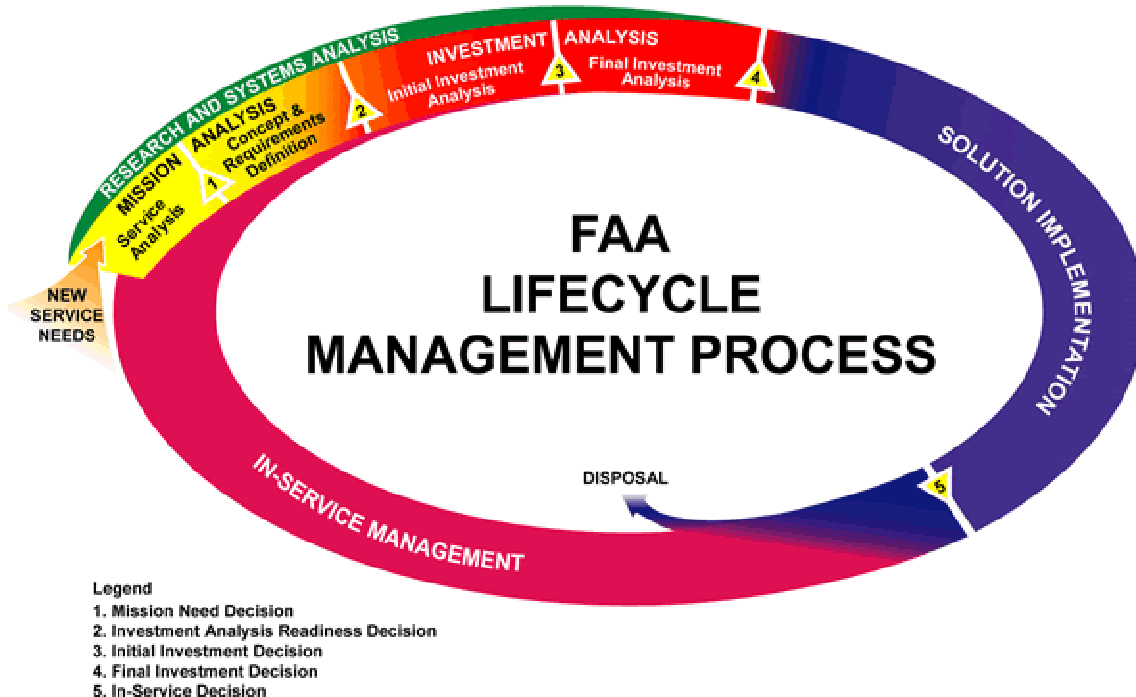


Figure 3.1-1. FAA AMS Lifecycle Management Process

The process contains five major decision points at which the Enterprise investment authority may make decisions to continue or cancel the program based on performance or other factors.

SE is conducted and documented throughout the lifecycle process, which spans individual investment programs across the National Airspace System (NAS). SE ensures integration across the NAS for service-level capabilities to achieve an efficient and fully interoperable NAS. At the program level, SE optimizes performance, benefits, operations, and lifecycle cost.

3.1.2 Relationships Between SE Elements

Chapter 1 (see Table 1.2-1) listed the SE elements. This chapter discusses the relationships among the SE elements by describing the inputs to and the outputs from the various elements. An approach describing these interrelationships uses an N-squared (N^2) diagram for the SE elements.

The **N^2 diagram** is a systematic approach to identify, define, tabulate, design, and analyze the relationships between the set of SE elements that comprise the FAA process defined in this SEM. It can also be used to characterize relationships between functional and physical interfaces. The “N” in an N^2 chart (an $N \times N$ matrix) is the number of entities for which relationships are shown. In this case, it is the set of 13 SE elements in Table 1.2-1. They appear along the diagonal axis. The remainder of the squares in the matrix contain interface inputs and outputs. The contents of each intersection of the rows and columns interconnecting any two elements indicate the interface between those elements in the form of inputs and outputs. The outputs appear on the horizontal rows, while the vertical columns indicate inputs. Data flows in a clockwise direction between elements. **Figure 3.1-2** shows the SE elements along the diagonal of the **N^2 diagram**, with the other matrix entries indicating the inputs, outputs, and product relationships between the SE elements by tracing the intersections of rows and columns.

Figure 3.1-2. System Engineering Functional N^2 Diagram

3.2 SE Elements and the AMS Lifecycle Phases

The program lifecycle includes all activities and products associated with a system, from initial concept to disposal. This aligns with the global aspects of SE’s definition. Definitions of the program lifecycle phases serve different purposes for different SE elements. Table 3.2-1 shows the FAA SE elements and their association with each of the AMS phases.

Table 3.2-1. Relationship Between SE Elements and AMS Phases

SE Element													
AMS Lifecycle Phase	Integrated Technical Planning	Requirements Management	Functional Analysis	Synthesis	Trade Studies	Interface Management	Specialty Engineering	Integrity of Analyses	Risk Management	Configuration Management	Validation and Verification	Lifecycle Engineering	Maintain System Engineering
Mission Analysis	X	X	X	X	X	X	X	X	X		X	X	
Investment Analysis	X	X	X	X	X	X	X	X	X	X	X	X	X
Solution Implementation	X	X	X	X	X	X	X	X	X	X	X	X	X
In-Service Management	X	X	X	X	X	X	X	X	X	X	X	X	X
Disposal	X				X	X	X		X	X		X	

3.3 Associating SE Milestones With AMS Phases

SE reviews and milestones are associated with and support various AMS decision points. These SE milestones are the primary means to measure a program's progress. The reviews and milestones are detailed in subsection 4.2.6 (in Section 4.2, Integrated Technical Planning) and summarized in the following paragraphs (by AMS decision point):

- **Mission Need Decision (AMS-1).** In support of the AMS-1 decision point, analysis is conducted to determine what capabilities must be in place now and in the future to meet agency goals and the service needs of stakeholders. The primary analysis output is a service-level mission need for each service organization. The major SE input to this decision is a recommendation on candidate technologies to be considered and an identification of the shortfall to be addressed. The candidate technology recommendation is an output of a Technology Readiness Assessment (TRA).
- **Investment Analysis Readiness Decision (AMS-2).** Subsequent to the AMS-1 decision, a concept and requirements development activity is conducted, which results in an Investment Analysis Readiness Decision (IARD). SE provides inputs to this decision through the results of an SE Investment Analysis Review (SIAR), which determines if there is sufficient SE data available for a viable decision.
- **Initial Investment Decision (AMS-3).** The initial investment effort explores possible alternative technology or operational solutions to satisfy the mission shortfalls identified in AMS-1. The AMS-3 decision evaluates the most promising solution(s) for further refinement before a final decision. SE conducts a Functional Baseline Review (FBR) to support the Initial Investment Decision and establishes the functional baseline for the investment.
- **Final Investment Decision (AMS-4).** Completion of the Investment Analysis effort is marked by an investment decision. This decision point selects the actual solution in which to invest. A System Requirements Review (SRR) is conducted to validate that the program requirements are sufficient to support the investment decision.
- **In-Service Decision (AMS-5).** The In-Service Review checklist is reviewed by the appointed decision authority as part of the In-Service Decision. Several SE milestones, such as the Preliminary Design Review (PDR) and Critical Design Review (CDR), are established as quality gates leading up to this decision point.

3.3.1 SE Milestones and Products Associated With the Product Development Process

Figure 3.3-1 depicts the relationship between the SE milestones, associated SE products, and the AMS decision points for each AMS phase. The following subsections correlate the SE milestones with each phase and decision gate(s) of the AMS lifecycle shown in Figure 3.3-1. Data flow diagrams in subsequent figures highlight the SE processes and work products that are predominant during the associated AMS phase. See subsection 4.2.6 (in Section 4.2, Integrated Technical Planning) for further details on these reviews and milestones.

Product Planning & Development Process

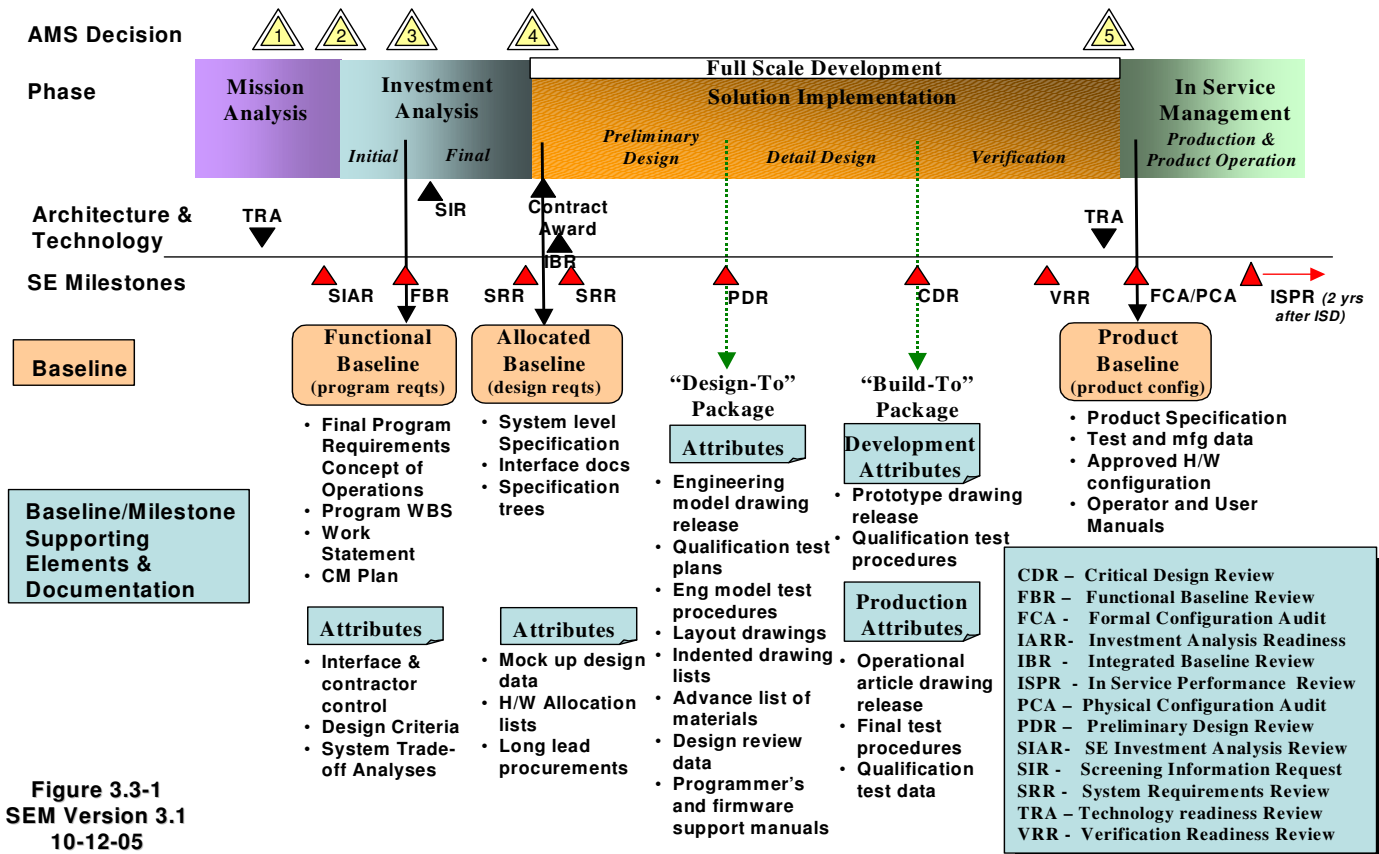


Figure 3.3-1
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Figure 3.3-1 Product Planning & Development Process

3.3.2 FAA Framework

Table 3.3-1 further expands Figure 3.3-1 to:

- Identify the SE milestones and SE work product outputs associated with the SE milestone
- Show the AMS decision gates and relate the SE effort to these gates
- Account for the new Exhibit 300 products in the AMS and the SE contributions to these products

Table 3.3-1. FAA SE Lifecycle Framework

AMS Lifecycle Phase	SE Milestone Entry Criteria	SE Milestone	SE Milestone Output (SE Products Only)	AMS Investment Decision Gate
Mission Analysis				
Corporate	<ul style="list-style-type: none"> • Enterprise Architecture • Concept of Operations (CONOPS) • Concerns and Issues • Technology • Market Research • Need • Corporate Strategy and Goals • Legacy System 	Technology Readiness Assessment (TRA) — A multi-disciplined technical review that assesses the maturity of Critical Technology Elements (CTEs) being considered to address user needs; analyzes operational capabilities and environmental constraints within the Enterprise Architecture (EA) framework.	<ul style="list-style-type: none"> • Validated NAS Functional portion of EA • Technology opportunities • Updated Risk Assessment • Gap Analysis 	
Service level	<ul style="list-style-type: none"> • CONOPS • Gap Analysis • Standards • Guidance and Tools for Service level MA 		<ul style="list-style-type: none"> • Functional Architecture • Service Level Mission Need (SLMN) 	1. Mission Need Decision (new)
Concepts and Requirements definition	<ul style="list-style-type: none"> • Preliminary Concept of Use (CONUSE) • FAA Policy • Standards • Preliminary Operational Services and Environmental Description (OSD) • Constraints • Integrated Program Schedule • Initial Description of 	SE Investment Analysis Review (SIAR) — A review to determine if the mission need capabilities shortfall and attendant solution set of alternatives (i.e., a valid set of concepts and preliminary requirements, technical constraints, and the list of risks) are complete enough to support a Mission Need Decision.	<ul style="list-style-type: none"> • Preliminary Exhibit 300 Attachment 1 (preliminary Program requirements (pPR) — previously the Initial Requirements Document (iRD) • Final Description of Alternatives • Lifecycle Cost Estimate • OSD • CONUSE 	2. Investment Analysis Readiness Decision (formerly JRC 1)

AMS Lifecycle Phase	SE Milestone Entry Criteria	SE Milestone	SE Milestone Output (SE Products Only)	AMS Investment Decision Gate
	Alternatives <ul style="list-style-type: none"> • SLMN 			
Investment Analysis				
Initial	<ul style="list-style-type: none"> • Preliminary Exhibit 300 Attachment 1 (pPR - previously the iRD) • Constraints • FAA Policy • Standards • Integrated Master Schedule (IMS) • Investment risks 	Functional Baseline Review (FBR) — A formal review to ensure that requirements have been completely and properly identified and that there is a mutual understanding between the implementing organization and stakeholders. It captures functional requirements that result from Mission Analysis and Investment Analysis phases.	<ul style="list-style-type: none"> • Final Requirements Set - Exhibit 300 Attachment 1 (fPR — previously the Final Requirements Document (fRD)) • Program Work Breakdown Structure (WBS) • Program Statement of Work (SOW) • Final System Engineering Management Plan (SEMP) 	3. Initial Investment Decision (formerly JRC 2a)
Final	<ul style="list-style-type: none"> • final Program Requirements (fPR) • Architecture Impacts • Risks • IMS • Life Cycle Engineering (LCE) cost estimate of each alternative • Draft Interface documents 	<i>(Program level)</i> System Requirements Review (SRR) — An internal FAA review to ensure that all the top-level requirements have been completely and properly identified and are correct. It is generally conducted just prior to AMS Investment Milestone 4. It validates program cost, schedule, and performance to support Milestone approvals. It establishes the Allocated baseline as the governing technical description, which is required before proceeding to the next	<ul style="list-style-type: none"> • System Specification • Risks for recommended alternative • LCE cost estimate for recommended alternative • Draft ISR Checklist • Interface documents • (Contractor) SOW 	4. Final Investment Decision (formerly JRC 2b)

AMS Lifecycle Phase	SE Milestone Entry Criteria	SE Milestone	SE Milestone Output (SE Products Only)	AMS Investment Decision Gate
		AMS phase.		
Solution Implementation				
	<ul style="list-style-type: none"> • System specification • SOW • Contract WBS 	(Contractor level) System Requirements Review (SRR) — A formal, system-level review conducted to ensure that system requirements have been completely and properly identified and that a mutual understanding between the government and contractor exists.	<ul style="list-style-type: none"> • Agreement on system specifications 	
Preliminary design	<ul style="list-style-type: none"> • Completed allocated baseline as documented in design specifications for each hardware and software configuration item 	Preliminary Design Review (PDR) — A formal review of initial design concepts and documentation to confirm the preliminary design logically follows the SRR findings, meets requirements, and to further define physical and functional interface requirements. It normally results in approval to begin detailed design.	<ul style="list-style-type: none"> • (Approval to begin detail design) • Risks • Request for Action (RFA) 	
Detail design	<ul style="list-style-type: none"> • Completed design package for each hardware and software configuration item 	Critical Design Review (CDR) — A formal review conducted to evaluate the completeness of the design, its interfaces, and suitability to start initial manufacturing.	<ul style="list-style-type: none"> • (Approval to begin fabrication) • Risks • RFA 	

AMS Lifecycle Phase	SE Milestone Entry Criteria	SE Milestone	SE Milestone Output (SE Products Only)	AMS Investment Decision Gate
Verification Verification (continued)	<ul style="list-style-type: none"> • System definition is under formal configuration control • All verification plans approved • Draft verification procedures available • Verification assets/resources identified and available 	Verification Readiness Review (VRR) — A formal review conducted to ensure that all SE considerations are satisfied and that the readiness of all support, test, and operational systems is in order to perform the Verification process.	<ul style="list-style-type: none"> • (Approval to begin formal verification) • Risks • Detailed verification procedures 	
	<ul style="list-style-type: none"> • Verification program complete • Reports approved • Verification article configuration compliance to design package established 	Functional Configuration Audit (FCA) — A formal review to verify that the system and all subsystems can perform all of their required design functions in accordance with their functional and allocated configuration baselines.	<ul style="list-style-type: none"> • Configuration reconciliation list • Gap of required versus verified performance 	
	<ul style="list-style-type: none"> • Technical data package complete • Quality control results available • Manufacturing and quality control plans complete • FCA complete • Configuration differences between FCA and PCA units reconciled 	Physical Configuration Audit (PCA) — A formal audit that establishes the product baseline as reflected in an early production configuration item. The audit determines whether the system was built in accordance with the design package reviewed at the CDR.	<ul style="list-style-type: none"> • Baselined hardware and software configuration • Operator and user manuals 	5. In-Service Decision (same)

AMS Lifecycle Phase	SE Milestone Entry Criteria	SE Milestone	SE Milestone Output (SE Products Only)	AMS Investment Decision Gate
In-Service Management				
	<ul style="list-style-type: none"> • Lifecycle metrics and benefits • Operational Risk list 	In-Service Performance Review (ISPR) — A formal technical review to characterize In-Service technical and operational health of the deployed system by providing an assessment of risk, readiness, technical status, and trends in a measurable form that will substantiate In-Service support, budget priorities, and/or possible disposal.	<ul style="list-style-type: none"> • Continued investment recommendation 	

3.4 AMS Program Phases

3.4.1 Mission Analysis Phase

3.4.1.1 Mission Analysis Phase Objectives

The basic objectives of the Mission Analysis (MA) phase are to identify a capability shortfall, quantify a need, and identify potential technological opportunities to address that need. Nonmaterial solutions are also evaluated during this phase. In most cases, the MA consists of activities to validate high-level needs and to seek approval to proceed to the Investment Analysis phase. Mission Analysis has two dimensions: a technical dimension and a program-planning dimension. The technical dimension ensures that a complete understanding of the demand for services has been identified and quantified. This is accompanied by identification and quantification of existing and projected supply of services. The program-planning dimension identifies potential project-scope and estimated resource requirements. The primary outputs of this phase are the final Service Level Mission Need (SLMN); a preliminary Program Requirements (pPR) set documented in a Preliminary Exhibit 300 Attachment 1; definition of Alternatives; a Concept of Use; and an Initial Investment Analysis Plan. The MA phase ends with approval to execute the Investment Analysis Plan, which is obtained at the Investment Analysis Readiness Decision (see Decision #2 in Figure 3.3-1). Figure 3.4-1 is an overview of the primary SE activities that occur during MA.

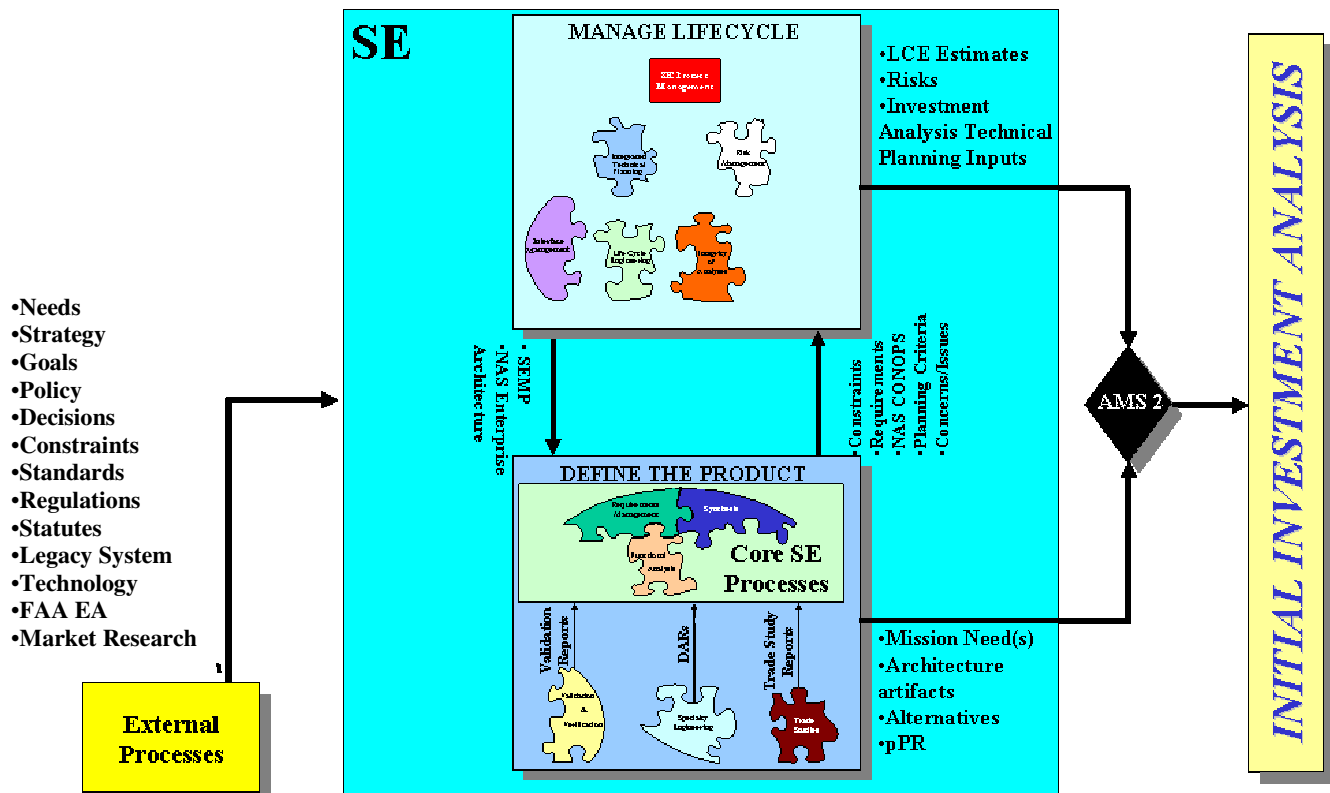


Figure 3.4-1. Mission Analysis System Engineering Inputs and Outputs

3.4.1.2 Mission Analysis SE Activities

SE is initiated when a stakeholder need is recognized and is used to understand what is required functionally to meet the stated need. A system Concept of Use (CONUSE) is developed via Functional Analysis (Section 4.4) and is used by Requirements Management (Section 4.3) to develop an SLMN to address the need or shortfall. The interaction of these two processes results in a high-level functional decomposition and, likewise, a high-level requirements decomposition. The resulting set of requirements is validated and is used, along with the high-level functional architecture, during the Synthesis process (Section 4.5) to develop a description of alternatives and associated design constraints. In addition to the core Functional Analysis, Requirements Management, and Synthesis activities, other SE processes are initiated during the MA phase. These activities involve technical planning to provide program management and guidance on planning both management and SE activities throughout the system's lifecycle. This planning is required to provide proper guidance for SE activities, including identifying risks and plans to mitigate those risks and establishing analysis criteria for the various analyses that occur during system design. Any of the SE activities may surface concerns and issues for handling by Risk Management (Section 4.10) as well as constraints to bound the activities of the Trade Studies process (Section 4.6).

EIA standard 731 defines a constraint as (1) a restriction, limit, or regulation or (2) a type of requirement that is not tradable against other requirements. Often, constraints are defined in work-scope statements provided by project contributors during the cost definition process. This includes gathering stakeholder inputs on "needs," system constraints (costs, technology limitations, and applicable specifications and legal requirements), and system "drivers" (such as competition capabilities and critical environments). It is recommended that tradeoffs be done regarding the desirability of including a performance capability in the system versus a more

affordable (or less risky) system approach. This tradeoff process often begins well before a firm set of needs is established and continues throughout the MA phase during which stakeholder interaction on specific items proposed may occur. Constraints may be further adjusted throughout later AMS phases. Like behavior deficiencies or shortfalls, these are excellent opportunities for preplanned product improvement. Funding, personnel, facilities, manufacturing capability, critical resources, or other reasons may cause constraints. The reason for each constraint needs to be readily understood.

3.4.2 Investment Analysis Phase

3.4.2.1 Investment Analysis Phase Objectives

The Investment Analysis phase of the AMS lifecycle has the following objectives:

- Further translate the SLMN and supporting requirements into lower level requirements and eventually into functional specifications
- Select the balanced solution that meets cost, schedule, performance, and political considerations
- Refine the solution from a NAS perspective
- Modify the NAS enterprise architecture to the recommended solution
- Complete all program plans
- Complete the functional architecture to a level appropriate to requirements (i.e., those levels needed to support development of the final requirements and system specification)
- List and analyze risks associated with alternatives considered
- Provide risk mitigation plans with associated costs

The Investment Analysis phase of the AMS begins with the IARD and ends with a Final Investment Decision. The readiness decision determines whether the SLMN, CONUSE, preliminary requirements, and initial alternatives are sufficiently defined to warrant entry into investment analysis. The decision is made within context of all ongoing and planned investment activities to sustain and improve service delivery.

There are two stages of the Investment Analysis phase: the initial stage, which leads to selection of the alternative(s) offering the most promising benefits during AMS Decision Gate #3; and the final stage, which fleshes out the implementation details of the selected alternative(s) for an investment decision to authorize implementation at AMS Decision Gate #4. This section treats Investment Analysis as a single phase with intermediate SE milestones, activities, and AMS decision criteria.

3.4.2.2 Investment Analysis SE Activities

Figure 3.4-2 lists the SE elements involved during the initial stage of Investment Analysis. The Functional Analysis (Section 4.4) initiated in the prior AMS phase continues to decompose functions to lower levels. These lower level functions are used to develop more detailed requirements that are, in turn, used to bound the next level of functional decomposition. Specialty Engineering (Section 4.8) feeds this process by providing various Design Analysis Reports to further refine the requirements and manage various risk facets. Requirements generated from this interaction are validated and provided to the Synthesis process (Section 4.5), where alternative solutions to meet these requirements are developed and refined. A

business case is developed that documents all stakeholder costs and obligations, providing details of both agency and nonagency resource demands.

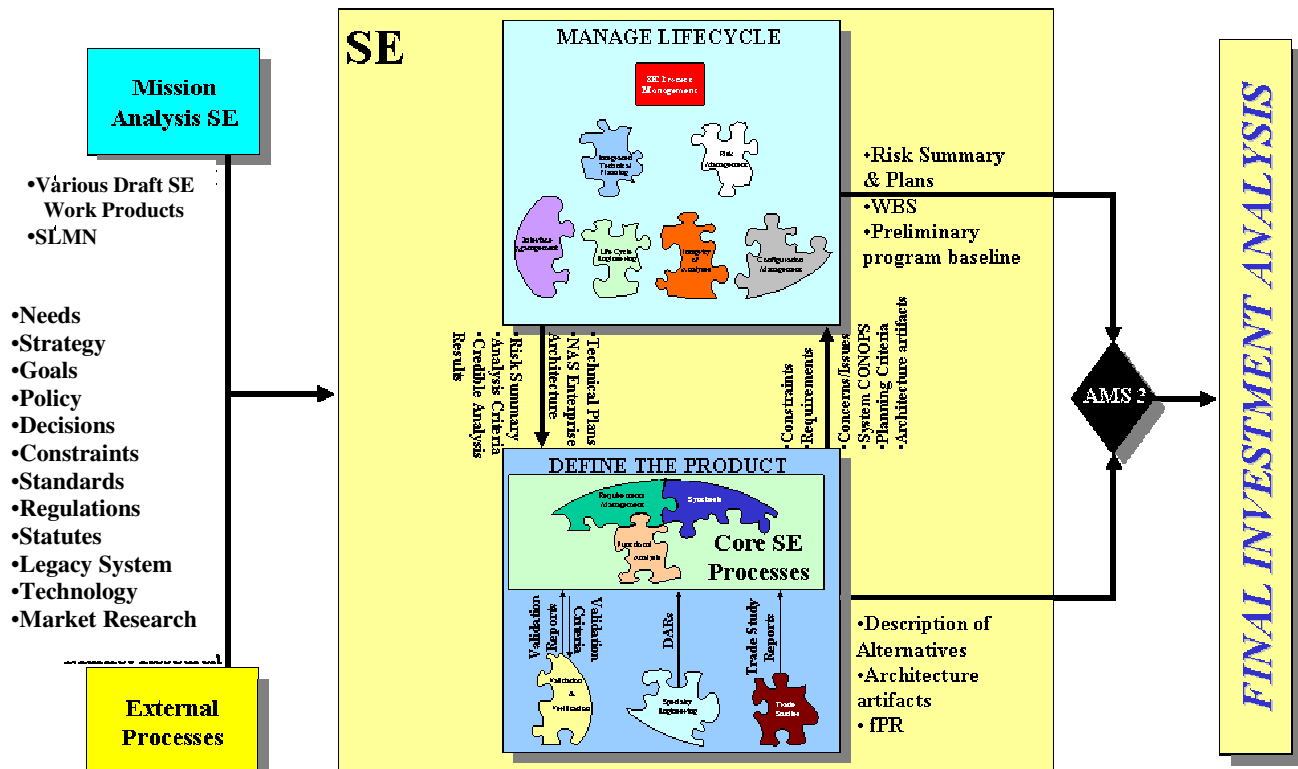


Figure 3.4-2. Initial Investment Analysis System Engineering Inputs and Outputs

When the business case sufficiently matures, the results of the initial analysis efforts and recommendations are presented to the JRC for approval to pursue the preferred solution. Implementation of that decision involves continued refinement of the business case and the SE products that support it. Figure 3.4-3 lists the SE elements involved during the second portion of Investment Analysis.

The primary outputs from the SE efforts in this AMS phase are the functional and physical architectures and associated requirements that are used to support a decision to invest in the selected solution. Table 3.3-1 (above) shows the SE products, inputs, and outputs required to complete the associated AMS milestones #3 and #4, which are the major AMS investment decision gates for this lifecycle phase.

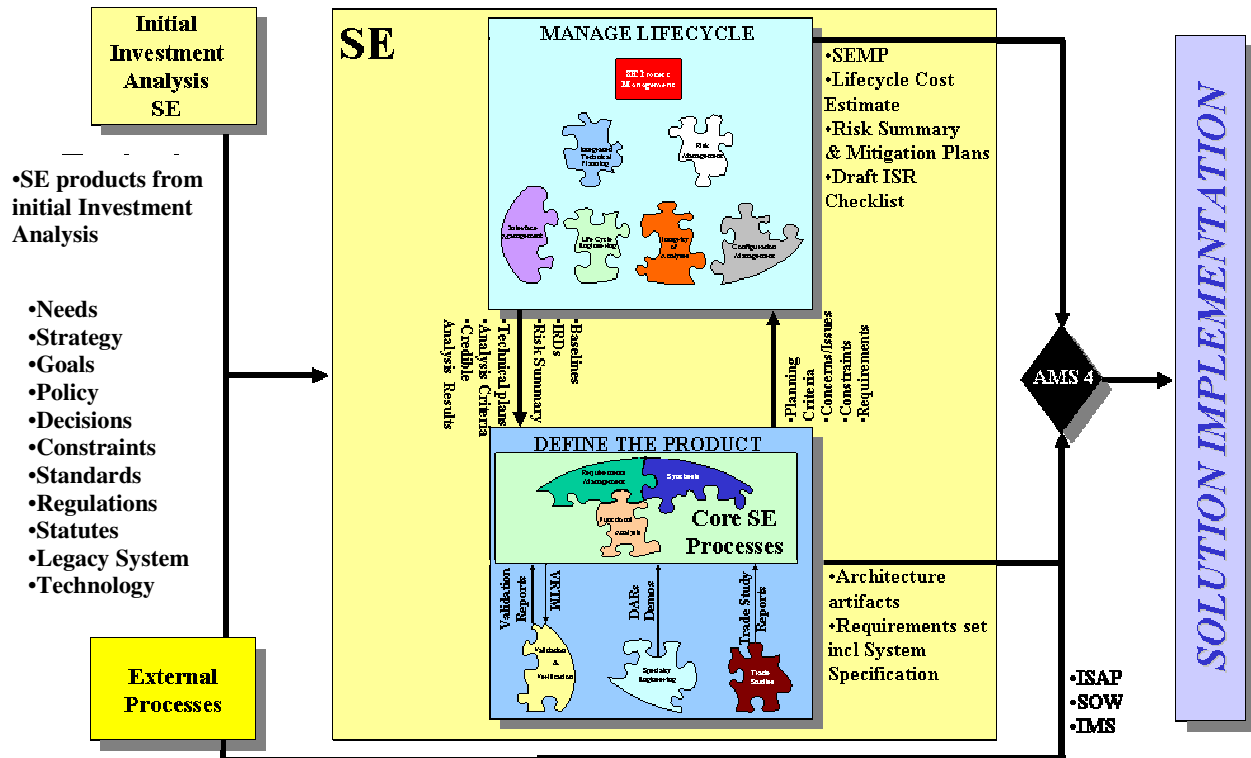


Figure 3.4-3. Final Investment Analysis System Engineering Inputs and Outputs

3.4.3 Solution Implementation Phase

3.4.3.1 Solution Implementation Phase Objectives

The Solution Implementation phase of AMS begins with the final Investment decision (AMS Decision Point #4), during which an acquisition program is established for the solution selected and ends when the new capability goes into service (i.e., when a new service or capability is commissioned into operational use at all sites).

Detailed program planning, including the solicitation and evaluation of offers for prime contract(s), occurs during final investment analysis and before the final investment decision. This ensures that accurate contract costs, risks, and schedules are reflected in the Exhibit 300 Program Baseline and its attachments. These plans and baselines are revalidated and updated if necessary after contract award to ensure that they can realistically serve as the management construct for program implementation. The Exhibit 300 Program Baseline and its attachments are maintained and kept current throughout Solution Implementation.

The overarching goal of Solution Implementation is to satisfy user requirements and achieve the benefit targets in the Exhibit 300 Program Baseline. Activities that occur during Solution Implementation vary widely and are tailored for the solution or capability being implemented. The primary outcome of Solution Implementation is a fully deployed and supported operational capability that satisfies requirements, is accepted by users, is compatible with other products and services in the field, and realizes the benefits in the program baseline.

3.4.3.2 SE Activities of Solution Implementation Phase

Figure 3.4-4 lists the SE elements activities required to accomplish the Solution Implementation objectives. While the SE activities vary widely from program to program, the interactions of the SE elements remain essentially the same as in the Investment Analysis phase. Upfront activities involve finalizing and baselining the system, its requirements, and the program to support its development and operation. The SE effort then focuses on transforming the accepted requirement set into a product for deployment. Thus, toward the beginning of the phase, the emphasis remains on the core SE processes, which continue to refine the requirements and bring greater resolution to the design. In the latter portion of this phase, the emphasis shifts to Verification activities (Section 4.12) to verify that the system has been built and integrated according to the requirements. The final set of Solution Implementation activities consists of installing the product or initiating the service at each site and certifying it for operational use. As in previous stages of SE efforts, it is recommended that each SE element active during this phase surface concerns and issues that present risk to the program.

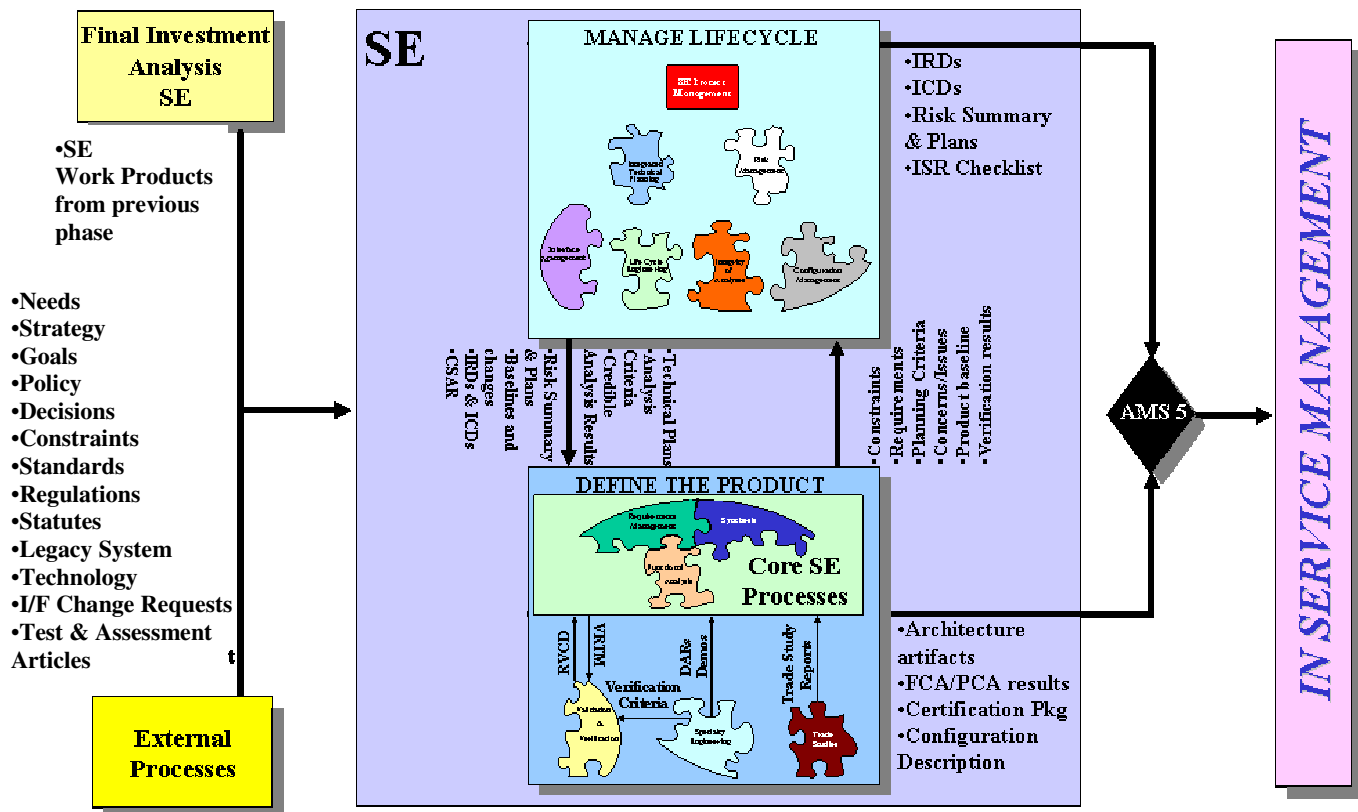


Figure 3.4-4. Solution Implementation System Engineering Inputs and Outputs

Various SE milestones—in the form of reviews and audits (discussed in Section 4.2 (Integrated Technical Planning) and illustrated in Figure 3.3-1) — are conducted throughout the development effort to maintain proper oversight of system development and maturation.

Depending on the nature and scope of the acquisition involved, the SE activities conducted during Solution Implementation vary widely. For example, activities associated with buying and deploying a commercial product involve different tasks and risks than a product requiring full development. The main objective of this phase is to successfully complete the necessary

actions and activities to obtain the solution and to accept a product or service for operational use. For most acquisitions, the solution will be required to interface with at least some segment(s) of the NAS legacy system.

3.4.4 In-Service Management

In-Service Management involves two distinct sets of work activities. The first set monitors and assesses the real-world performance of the system against its requirements and expected benefits in the approved program baseline and takes action to optimize performance throughout its operational life. The second set of activities deals with operating and maintaining the system and its physical and support infrastructure throughout its service life. Both sets employ the various SE elements that appear in Figure 3.4-5. The results of SE efforts are used to support the decision-making process regarding when a new or improved capability is needed.

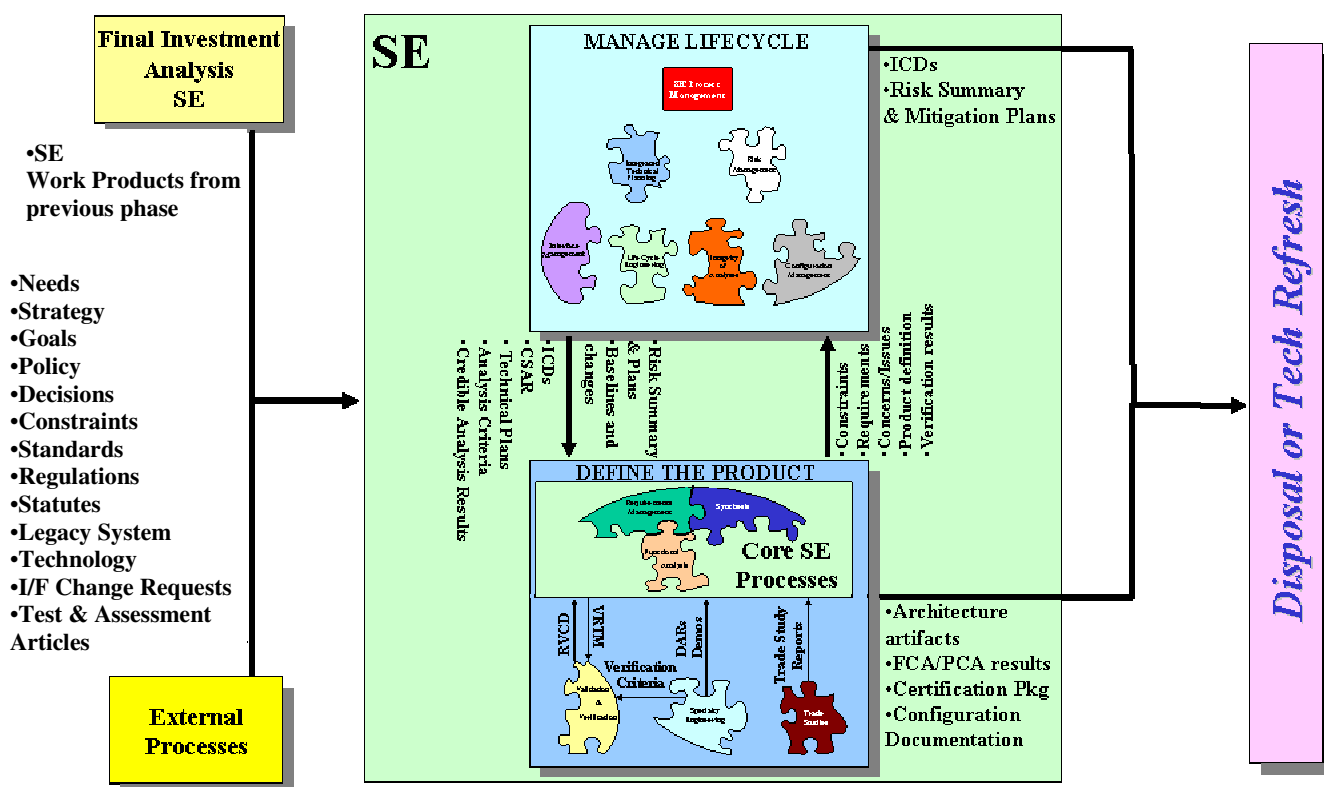


Figure 3.4-5. In-Service Management System Engineering Inputs and Outputs

In-Service decision making needs to take two factors into account: (1) assessing the timing for technology insertion or capability replacement, and (2) whether modifications or improvements are feasible within the approved sustainment baseline funding. If an engineering change to the system within the sustainment funding is unable to be supported, then the shortfall is addressed via the standard AMS lifecycle phases. If the effort to modify and/or optimize system performance is within the scope of sustaining funds, then the various SE elements are employed as in the Solution Implementation phase but on a lesser scale. The specific SE process application and associated level of effort depend on the scope of the upgrade.

3.4.5 Disposal

The SE efforts concerning disposal of a legacy system occur during the investment analysis of potential replacement alternatives and are shown in Figure 3.4-6. Disposal of the legacy system occurs during the replacement solution's Solution Implementation phase. Lifecycle Engineering (Section 4.13) defines the process for planning and executing disposal activities. The Integrated Technical Planning process (Section 4.2) is used to develop a Disposal Plan under FAA Order 4800.2, Utilization and Disposal of Excess and Surplus Personal Property.

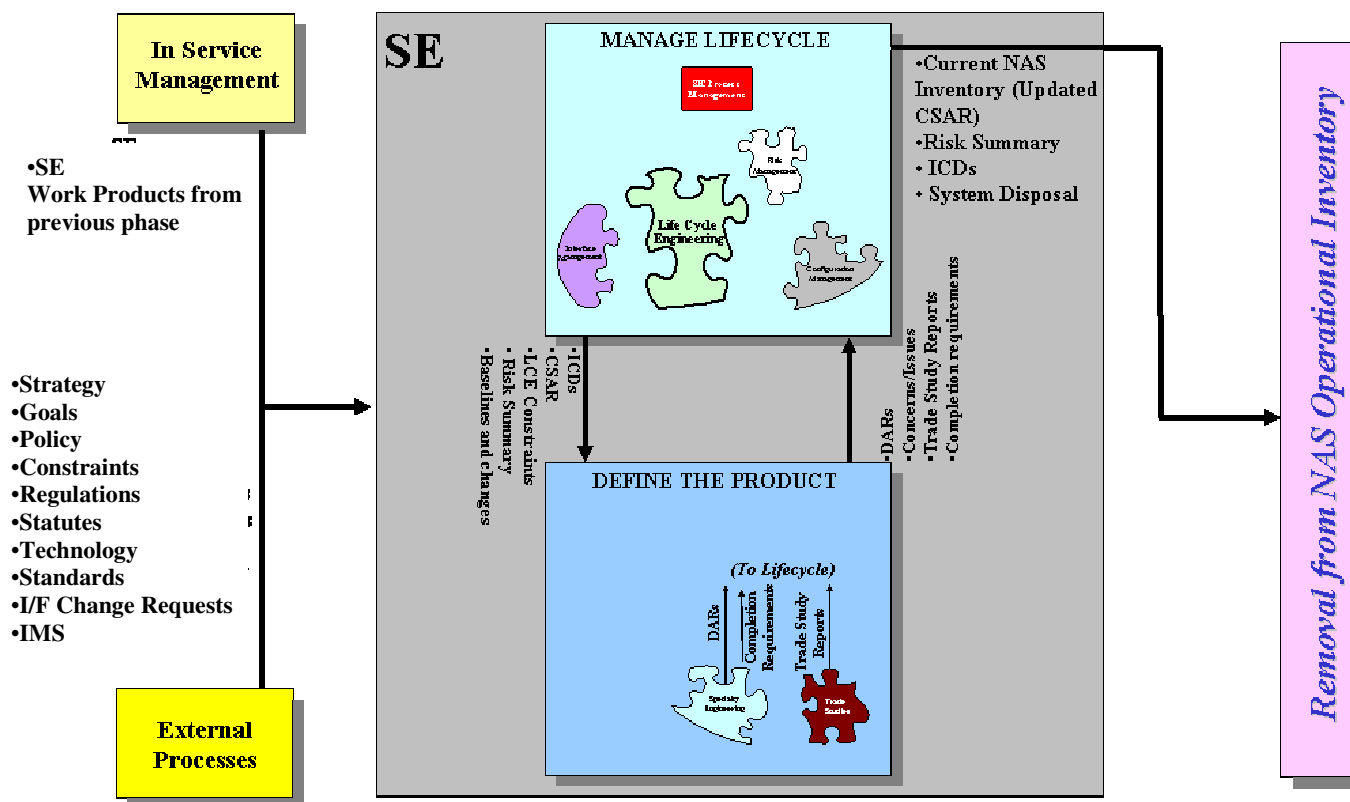


Figure 3.4-6. Disposal Phase System Engineering Inputs and Outputs

